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# **AFFORDABLE MONSOON RAIN MITIGATION MEASURES IN THE WORLD HERITAGE SITE OF MOENJODARO, PAKISTAN**

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## **ABSTRACT**

The paper provides an overview of environmental monitoring, monsoon rain deterioration effects, and affordable monitoring measures implemented in the 52km of exposed walls of the Bronze Age archaeological site of Moenjodaro (Sindh, Pakistan). The site was first excavated in 1922 and, after inscription in the UNESCO World Heritage List in 1980, it became the experimental ground for several national and international consultants who advised on wide ranging protection and consolidation methods against monsoon rain attack.

The aim of this paper is to make a review of affordable traditional mitigation measures in use at the site, and of their effect in terms of heavy rain defence. More recent mitigation techniques are examined also, and their effectiveness in terms of heavy rain defence is discussed. Finally, a case study on the monsoon preparation work carried out in two areas of Moenjodaro is examined.

**Keywords:** monsoon deterioration effects, fired brick, World Heritage site, archaeological site, conservation

## **1. THE SITE**

The World Heritage site of Moenjodaro is located in Sind about 400Km north of Karachi and 32km south of Larkana. The site lays on the bank of the river Indus (Figure 1) and is believed to have flourished from 2350 to 1800 BC<sup>1</sup>. Moenjodaro was one of the main centres of the Harappan civilization and it was constructed with two building materials: mud brick (10x20x40cm), and fired brick (6.3x13.4x27.9cm) bonded with mud mortar<sup>2</sup>. In contrast with other settlements of the same period, the Harappan cities were built mostly with fired brick whilst little use was made of mud brick as walling material. According to Cooper and Dawson (1989) this is due to the fact that the site is built on an alluvial floodplain, and to stronger resistance of fired brick to floods.

## **2. MONITORING DIURNAL ENVIRONMENTAL DATA**

Monitoring of environmental data (temperature, RH, rainfall) is carried out by the Moenjodaro Water and Soil Investigation Laboratory (WASIL) and is patchy due to poor management. Furthermore, only in recent years this data was transferred from logbooks to Excel files and only one person from the Department of Archaeology and Museums has received training to do so.

Climate on the site is represented by extreme temperature that can reach 47°C in May-June (Figure 2). Rainwater run-off is a major threat to Moenjodaro, monsoon precipitation being quite intense in June. For instance, the study of 2004 rainfall data shows that precipitation concentrates in the winter (19.5mm between December and January) and during the monsoon season (7.1mm in June). Rainfall can be particularly intense during the monsoon period: it was calculated that a heavy storm of 60mm can take place easily in the site (Boekwijt 1979) and more recently, more than 200mm were observed in two days (Briscoe 1997).

Another influential aspect in Moenjodaro is represented by atmospheric moisture (or dew) and RH (monitored at the site, see Figure 3): sodium sulphate, the most common salt in the site, is hygroscopic and not only collects water from rising damp, but also from the air. A more detailed explanation of this phenomenon is given in section 4.6 and in Fodde (2008).

### 3. ASSESSMENT OF HEAVY RAIN AND MONSOON DAMAGE

#### 3.1 Introduction

The revised Master Plan for Moenjodaro (1997) explains that *'recent storms and heavy rainfall prove that previous archaeological intervention of storm-water drainage on the remaining structures is ineffective, and has in fact accelerated the structural damage.'* Monsoon precipitation is still a threat to Moenjodaro and damage is influenced by wind driven rain<sup>3</sup>, standing rainwater, and flowing water (run-off along the surface of masonry, but also along the ground surface). Wind driven rain has an influence on the structural stability of exposed walls that have missing capping and mud mortar joints weakened by erosion (Fodde and Khan 2010). If no maintenance is carried out, scouring can be so deep that individual bricks or portion of masonry can collapse, leading to more serious damage.

According to Jalbani and Briscoe (1995) *'deterioration and loss of important archaeological remains through surface erosion by rain run-off has been a problem at Moenjodaro since the beginning of excavations.'* This is also confirmed by Jansen (1988) who suggests that the consequential rebuilding of collapsed walls is a tradition that goes back to the 1920s. The destructive outcome of heavy rain and monsoon is described in the following sections.

#### 3.2 Wall collapse

Jalbani and Briscoe (1995) explain that in 1994 the disastrous effect of heavy rain was so extreme that 90 walls collapsed. Standing water or ponding enables the soil to reach its liquid limit, decreasing the structural capacity of the areas around walls and increasing slumping. The final outcome may be the collapse of walls especially if no water evacuation measures are into place. According to Herle et al. (2010) collapsible soils are the most problematic ones because they *'...have an open type structure with large void spaces giving rise to a metastable grain skeleton'* and monsoon or heavy rain can change their compression capacity, leading to structural problems. No measurements were ever taken of the levels of standing water in the site. This data would be crucial in planning mitigation measures. Readings could be taken easily with tape measurements on the walls of the most exposed areas.

#### 3.3 Scouring

Scouring occurs after heavy storms and this is worsened both by heterogeneous composition of soils around walls and by disintegration of clay particles due to salts attack. In fact the soil of Moenjodaro is characterised by salts crusts over a powdery soil which erodes easily due to lack of cohesiveness. Water runoff, uncontrolled drainage (Clifton 1980), and water undermining at wall bases have the effect of gradually removing the soil surface and of reducing its load carrying capacity (Drdacky and Asce 2010). Flowing water damage applies also to mud brick capping when no maintenance is carried out. In this case the corners are the most exposed, with preferential channels often leading to mud runoff on the vertical surface of walls.

#### 3.4 Gullying

Gullying, also called internal erosion, is common in soils with heterogeneous particle size. Herle et al. (2010) explain that internal erosion can be of two types: piping (in high hydraulicity gradients, when the washing of fine particles between coarse grained soils make the soil prone to collapse) and contact erosion (if soil is made in

layers of fine and coarse grains, the finer particles can be transferred between the pores of the coarse ones making the soil more permeable and susceptible to water erosion). This phenomenon is common in Moenjodaro and can have catastrophic consequences for the walls if gullies are not identified and repaired either by ramming salt free soil or by paving important areas with mud bricks on edge.

### **3.5 Water table fluctuation and ground water control**

Another threat is represented by the rise in sub-soil water. The ground water table varies both in winter and summer due to which the capillary rise of water in the brickwork reaches up to 51m (AMSL, above mean sea level). The general water table as recorded during 1990-2000 varies from about 41-45m (AMSL). In 1972 a massive tubewells project was proposed with the aim of lowering the water table (Figure 4) and of reducing capillarity rise damage. In 1996 the running of tubewells was considered expensive due to the amount of power needed and the option of solar energy was considered. However, no action was taken and the tubewells started to be switched off and, since no maintenance was carried out, their decline followed.

## **4. TRADITIONAL MONSOON MITIGATION METHODS**

### **4.1 History of mitigation methods**

The history of Pakistan's flood and monsoon mitigation methods can be traced back to Prehistoric Baluchistan, when control of surface water was carried out with stone-faced embankments or dams called *gabar-bands* (Raikes and Dyson 1961). As for the specific case of the Indus civilization sites, archaeological evidence shows that in the Bronze Age city of Harappa a fired brick protective bund was constructed against floods. In Moenjodaro not only the citadel was built on a large mud brick platform against floods (Jansen 1985), but for the same reason smaller mud brick platforms were constructed as bases for single buildings (Beth et al, 2004). Cooper and Dawson (1989) mention that the platforms are rather made of fired brick, but actually this might be used only for the cladding of mud brick ramparts: *'the Indus valley, along which the civilization emerged, owes its fertility in part to annual flooding. Harappan towns are characterized by ramparts of burnt brick, raised as much for protection from monsoon inundation as from hostile armies. Permanent settlements built with this material allowed the inhabitants to exploit the surrounding flood plain's agricultural potential, generating sufficient wealth to finance the subcontinent's earliest surviving monuments<sup>4</sup>.'*

An important historic feature for the management of heavy precipitation is the impressive drainage system of collector channels that were built in many streets<sup>5</sup>. Amongst the first suggestions for drainage needs were those given by Marshall (1923) in his Conservation Manual: *'Proper provision is to be made of drainage, especially for taking off flood water after heavy rain. Water must not be allowed to stand about in pools or ditches near an ancient monument. The walls of many monuments are none too secure, and the scouring of earth away from their foundations may cause much damage. Drains should be made as inconspicuous as possible, but where stone or brick drains are necessary, they should be strongly built on concrete foundations and should not be liable to collapse or sinking or be in need of frequent repairs.'* Marshall's description, despite suggesting the construction of concrete foundations, shows that protection from flood and monsoon attack has a long history in the subcontinent.

It should be mentioned also that in Moenjodaro fired brick reconstruction of damaged buildings was influenced by major floods which are likely to have had a frequency of about every 140 years (Raikes and Dyson 1961).

#### **4.2 Description of soil employed in conservation**

Two salt-free soils are traditionally employed for the repair work: they are referred to by local craftsmen and conservators as 'clayey' and 'silty' soil<sup>6</sup>. Their use varies according to the type of work or part of the building. Table 1 provides the grain size distributions of such soils, but a full laboratory assessment of their effectiveness was not studied yet. It is proposed here that proper analytical work and test walls construction be carried out following the methodology developed by Fodde (2006). Clayey soil is employed for slurring, draining, and for masonry repair. Silty soil is used for wall capping and for the creation of shallow ponding. For instance, the reason behind the use of clayey soil for slurring is that empirical evidence has shown that it can leach out salts from the brick surface, and that this is preferable to sandy soil. For shallow ponding, both silty and sandy soils are employed because they allow water penetration and quick drying.

#### **4.3 Buttresses and mud *pushtas***

One of the most ancient mitigation systems at use in the site is represented by buttresses made with fired brick and mud mortar (Figure 5). This method dates back to the Indus valley civilization period when it was employed for preventing leaning walls from collapsing (Briscoe 1997), most probably due to reasons related to heavy rain and ponding.

Another interesting system against erosional loss is that of mud *pushtas* (Figure 6), which are employed also in neighbouring villages for the protection of vernacular earthen construction. The technique consists in the building of a continuous mud brick buttress around the perimeter of the wall. Compared to fired brick buttresses, mud *pushtas* have the advantage of being more flexible, less rigid, and accommodating more easily to uneven walls. One relevant aspect is that *pushtas* need to be limited in width in order not to be too disruptive (Briscoe 1997).

These approaches are adopted especially in the most visited areas, such as SD and DK-G, and less in other areas (Figure 1). To give an idea of their extent, the survey carried out by the authors in DK-G South area on 493 walls, with total length of 2954m, showed that fired brick buttress to support leaning wall were found on 6.5% of the walls and that mud *pushtas* were found on 5.3% of the walls.

#### **4.4 Wall capping**

Some of the horizontal wall surfaces are so wide that proper protection is needed against monsoon precipitation (Figure 7). Wall capping is widely applied in the site since 1956. This is confirmed by a survey carried out by the authors in the area called DK-G South on 493 walls<sup>7</sup> showing that wall capping with two courses of mud brick is present on 86.6% of the walls. The final outline of the top part of the walls follows that of the 'as found' state. The idea behind such soft capping is that of reversibility and of allowing regular maintenance through replacement of eroded parts.

Rain penetration in mud brick capping takes place in two stages: wind driven rain impacting on the vertical wall face and rainwater penetrating into the wall through cracks and lacunae. As a result, rainwater is trapped inside the wall and is eventually evacuated, leading to erosion of the core. Apart from the obvious protection from water penetration and erosion, it is believed that wall capping provides insulation from high temperature and consequential thermal movement. Furthermore, erosion

of mud brick capping and percolation of soil on the vertical wall surface of fired brick walls may provide further protection against salts attack (Briscoe 1997; Shaikh and Ashfaq 1981).

#### 4.5 Repointing

Repointing and resetting of loose brick are fundamental measures against heavy rain attack. The aim of this practice is to provide a barrier against water ingress. This is a measure that nevertheless needs to be properly implemented in the site and, despite being traditional, there is a general lack of understanding of the importance of sealing the joints with new mud mortar.

The repair material, the silty soil of Table 1, is selected according to the following parameters: reversibility of interventions, mortar to allow sacrificiality to the historic fired brick, and employment of only one type of pointing mortar to make the new intervention easily readable by future conservators-archaeologists (Fodde 2007). Repointing of joints is carried out by brushing loose parts with a soft brush, wetting in order to avoid suction, and by applying repointing mortar with a pointing tool. When the applied mortar loses some moisture due to suction, flat edged wooden plates are employed to allow proper packing and reduce shrinkage cracks.

#### 4.6 Mud slurring

Mud slurring, the expression employed by local craftsmen and conservators for mud washing, is carried out by creating a continuous layer of a 'mud paint' that covers the entire wall<sup>8</sup>, capping included (Figure 8). It is employed in the site as conservation measure against salts weathering, but it provides also protection against heavy rain attack. The technique is employed extensively and this is confirmed by a 2005 survey in DK-G South area on 493 walls, with total length of 2954m, showing that 90.3% of the walls are mud slurried. The application of mud slurry is controversial since 1993 when it was used for the first time in Moenjodaro. Since then the site changed from the typical red colour of fired brick to a brown which is more typical of mud brick. For such reason, uninformed visitors can be misled and believe that the site was actually built with mud brick only. However, according to Jansen (2003), the mud slurry or wash has a positive effect because it *'...brings back the original colour to the walls which were rendered with soil some 4500 years ago.'*

It should be noted here that sodium sulphate is the most common salt in Moenjodaro. Each molecule of sodium sulphate (thenardite,  $\text{Na}_2\text{SO}_4$ ), when hydrated, collects ten molecules of water, and at temperatures below 32.5 °C, the volume of crystals (mirabilite) can increase by 315% with catastrophic consequences for the brick. The idea behind the mud slurry is primarily that it acts as sacrificial layer against salts efflorescence so that crystallization occurs on the slurry and not on the brick face, as explained by Fodde (2007): *'...salts tend to crystallize in the slurry rather than in the brick by forming a crust made of salts and soil. To confirm this, after one year of application of the mud slurry, the analysis of such crusts has shown that they can contain as much as 50% salt by weight, proving that the slurry effectively works as a natural poulticing, but also suggesting that its constant replacement is needed.'* However, the layering of slurry can provide further sealing of joints and hence it can act as consolidation measure against heavy rains.

Weathering takes place especially at the wall base and this is due to the fact that Moenjodaro's ground has high soluble salts content. This is confirmed by Figure 9 which provides the ground soluble salts and moisture content from a depth of 200 cm to 0cm (surface). The diagramme shows that whilst sub soil moisture content

increases with the depth of the soil itself, soluble salts tend to increase towards the ground surface and this is due both to capillary action and to an increase in temperature. The obvious effect is that capillarity rise of water and salts solution has an influence on the weathering of walls.

## **5. RECENT MONSOON MITIGATION METHODS**

### **5.1 River training**

The river Indus flows at about 1Km east of the ruins of Moenjodaro, with floods being a common feature. According to the findings of Boekwijt (1979), the site is situated at 47m (AMSL) while the maximum flood level of the river Indus near the site reaches about 50m (AMSL). This is why the site was protected from river flood damage with five spurs and a dam<sup>9</sup> as visible in Figure 1 (see section 5.1).

River training and construction of T-shaped spur was carried out between 1986 and 1993 and was a major task, making the Moenjodaro project the most expensive amongst the UNESCO World Heritage sites. A total of five spurs of six metres of average height were constructed against river floods, the location of some of which can be seen in Figure 1. Ascon Bolan (1979) explains that the design parameters for the spurs were evaluated as being two: '*(i) highest flood level, and (ii) free board for providing safety over topping*', free board being the vertical distance between the high flood level and the top of the bund. Another important design parameter that was considered was a flood of 100 years return period. Spurs were constructed with local soil compacted at optimum moisture content and slopes were protected with stones from the quarry of Arore (Rohri) over a filter of gravel quarried from Dodanko (Ascon Bolan 1979).

### **5.2 Inadequate methods**

In the recent past the insertion of concrete drain pipes has been carried out undoubtedly at the expense of the historic fabric: in order to introduce the pipes, a great deal of original material has to be demolished. The negative effects of inserting horizontal and vertical damp proof coursing is due to the demolition of a large amount of original fabric (Figure 10) and is at present not employed in the site, one of the last interventions being documented in 2001 (Fodde 2007). Similarly to the insertion of damp proof coursing, wall underpinning can be destructive if carried out by unskilled craftsmen.

### **5.3 Suggestions**

Reburying and other passive techniques should be part of the conservation process (Hughes 1996). Reburial has been contemplated as a conservation measure in many sites and now is often referred to as the most effective technique for archaeological sites conservation (Woolfitt 2007; Agnew et al 2004). However, probably due to reasons related to the visibility and displaying of walls, so far this technique has not been contemplated for Moenjodaro.

Furthermore, it is suggested that the relevant data to be collected is wind driven rain, intensity, velocity, direction, and duration. Other important aspects are: effects of rain impact, run-off character, load transport, and rate of absorption. Comparing emergency conservation works with designated monitoring areas without emergency works is a key aspect. Recovery and long term slow changes should be recorded: effects on ground temperature, rate of ground drying out, rate of salt hydration.



## 6. SITE WORKS

The recommendations adopted by the 17th session of the international consultative committee for Moenjodaro (1997) suggest adopting compacted sweet soil (or soil with no salts) and mud brick as paving material for providing levelling and sloping to alleys and streets. The suggested gradient is between 1:200 and 1:400. Provision of proper gradient is done usually by replacing salty soil with sweet soil. This is a practice that goes back to the 1940s in Moenjodaro (Briscoe 1997). If carried out regularly, it is an effective measure for facilitating evacuation of water that would otherwise create deep gullies. Rows of mud bricks are employed as 'speed breakers', this being especially effective against monsoon attack (Briscoe 1997). As part of the monitoring regime the new gullies and drainage channels should be surveyed and marked on the map so that to form a basis for future drainage work (Jansen et al 1994). Study of erosion in relation to soil type and slope stabilization with local vegetation should be also carried out.

Draining rooms with no openings is one of the most difficult tasks. Such rooms tend to collect water that cannot be diverted otherwise and in such case the only non-disruptive measure is that of shallow ponding (Figures 10 and 11). This is undertaken by creating a depression or pool in the middle of the room so that water is eliminated by evaporation. Shallow trenching is made by digging a V shaped trench that has the aim of collecting water and diverting it to drainage areas (Briscoe 1997). When dealing with emergency conservation, low barriers are made by compacting loose soil in order to divert run-off water away from walls. Otherwise they are made with mud brick and seldom with fired brick.

Similarly to what explained for mud *pushtas*, wall bases are protected with loose soil that is rammed until damp proof course level. The aim of this measure is to divert water away from the walls and it is especially effective against monsoon attack (Briscoe 1997).

## 7. CASE STUDY: EMERGENCY MONSOON PREPARATION WORK IN DK-G AND MONEER AREAS

### 7.1 Introduction

A survey carried out by the authors in May 2005 shows that the most neglected and endangered areas were MN, VS, and DK-A-B-C. In most of the walls that belong to these areas the only conservation measure ever applied was mud slurring and capping. The main problem was that of structural stabilization, repointing, and provision of proper drainage facilities. It was also clear that the work load was so heavy that it would have been impossible to fully conserve such areas before the 2005 monsoon season. Another area that was tackled was DK-G. The selection of the area was dictated by the importance of the structures and by the necessity to improve drainage. The drainage work was carried out following the instructions provided by the 1997 *Manual for the Conservation and Maintenance of Moenjodaro* (UNESCO). The principles through which emergency drainage was carried out are the following: slowing down of water speed with the help of barriers and terracing made of mud bricks, collection of water away from the walls and towards drains where possible, employment of shallow ponding technique only where other techniques are not possible, complete avoidance of cutting through the walls to insert pipes or other devices, and use of *pushtas* to divert water away from wall bases. It was decided that such areas be prepared for the monsoon season by providing the methods explained in the following sections.

## **7.2 Selection of most suitable soil to be used as repair material**

In some areas sand was employed for paving rooms before applying a clay layer as it reduces crystallization of salts. The clay layer does not allow water penetration and its combined action with sand is very effective for shallow ponding (Figure 12). The selection and analysis of the most suitable soil was carried out in the WASIL laboratory and the main factor that influenced the selection was salts content and grain size distribution. Four samples were collected in different areas around Moenjodaro and the result of the conductivity test is explained in Table 2. Sample 3, being the most clayey and the least salty, was selected for mud slurring, whilst sample 4 was selected for the manufacturing of mud brick and for its employment as loose soil in drainage work.

## **7.3 Mud slurring and capping**

Because of the urgent nature of the work, mud slurring was applied only to loose walls and those in need of consolidation. It was therefore employed as a consolidation remedy and not as a salt leaching device, and the slurring for the latter purpose was applied later. Slurring was carried out before replacing the salty soil from the ground because if walls were brushed before the application of the slurry, salts would be collected at the base of the wall. Plastic sheets were employed to allow collection and removal of brushed salts. Water for slurring was collected from the Dadu canal because laboratory analysis showed low conductivity (100  $\mu\text{S}/\text{cm}$ ). Mud capping was applied to those walls that lacked protection or to those that needed maintenance. Capping was achieved by means of loose soil and not by employing mud bricks (Figure 7), as the first is a faster technique that was applied successfully by previous conservators. It was felt that the use of mud brick would slow down the preparatory work.

## **7.4 Removal of salty ground and replacement with sweet soil**

This was done with the help of a shovel and the portions of saline soil nearer to the walls were removed by means of brushes (Figure 13), so that to cause as little harm as possible to the bricks. The salty soil was accumulated in an area that could be reached by a tractor so that to allow easy disposal to a location outside the site boundary. Sweet soil was imported so that to improve drainage by creating sloping surfaces decreasing from the walls, and to allow water to be channeled towards the collector drain<sup>10</sup> (Figure 14).

## **7.5 Shallow ponding, creation of bunds, and provision of mud *pushtas***

Shallow ponding was created where water could not be diverted otherwise, especially in rooms with no door or exit. After removal of salty soil from the ground surface, the central portion of the room was cleaned from further debris so that to create a pond. Bunds were created where necessary in order to form a barrier against water. This was done by compacting sweet soil with a rammer so that to create a monolithic wall. Instead of building time-consuming mud brick *pushtas*, loose soil was rammed into layers until damp proof course level as barrier against water penetration and erosion. Figures 15-17 show a typical and representative room before and after emergency conservation work.

## **8. CONCLUSIONS**

The sheer size of the 52Km of exposed walls, together with extreme weather and salinity conditions, make the site of Moenjodaro a conservation challenge. The usefulness of the methods explained in this paper can be classified as being:

- At present research and interest are dynamic on defence measures against heavy precipitation and flooding. However, the specific literature is sparse and what is available does not focus on practical measures against torrential/monsoon rain;
- This paper describes affordable and immediate mitigation measures with the fundamental scope of being of use for the conservation of similar sites of the subcontinent;
- There is a need to support such measures with analytical work to enable a scientific assessment of the effectiveness of the proposed methods. At present effectiveness is guaranteed only by empirical evidence after decades of use, and this is a limitation. Integrating scientific approaches in building conservation is crucial.

Finally, the concept of monitoring is essential for considering carefully planned conservation measures against monsoon rain. The idea behind it is to predict events and how to deal with them, a practice that is not into place and that is quite needed in Moenjodaro.

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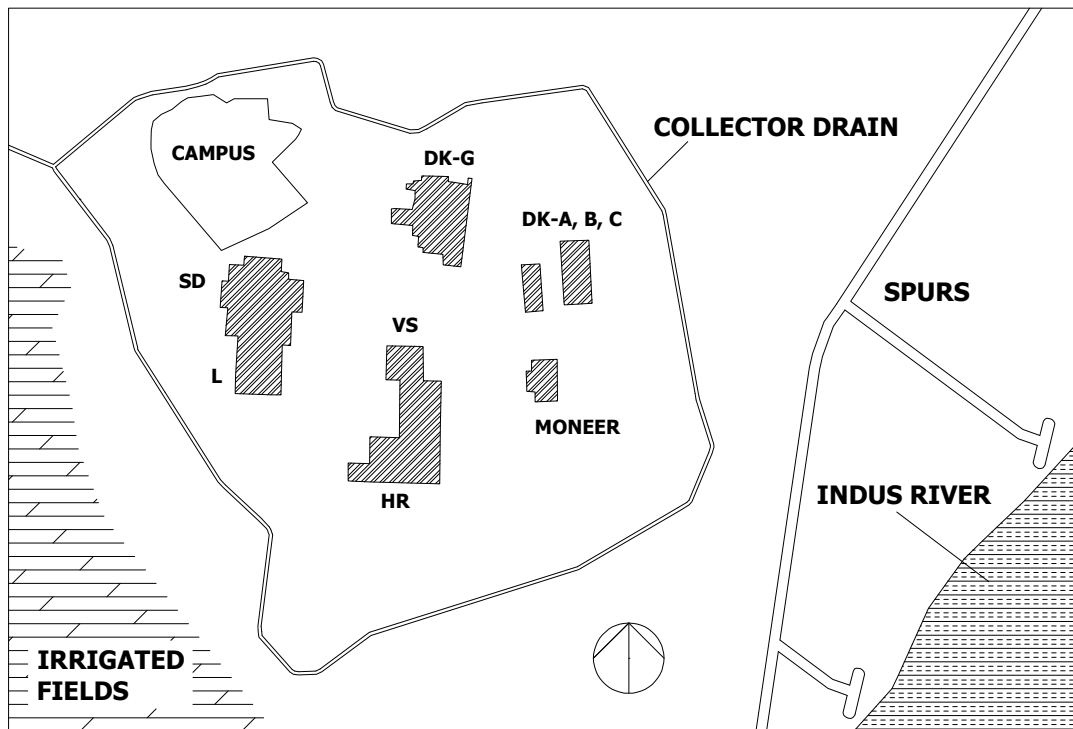
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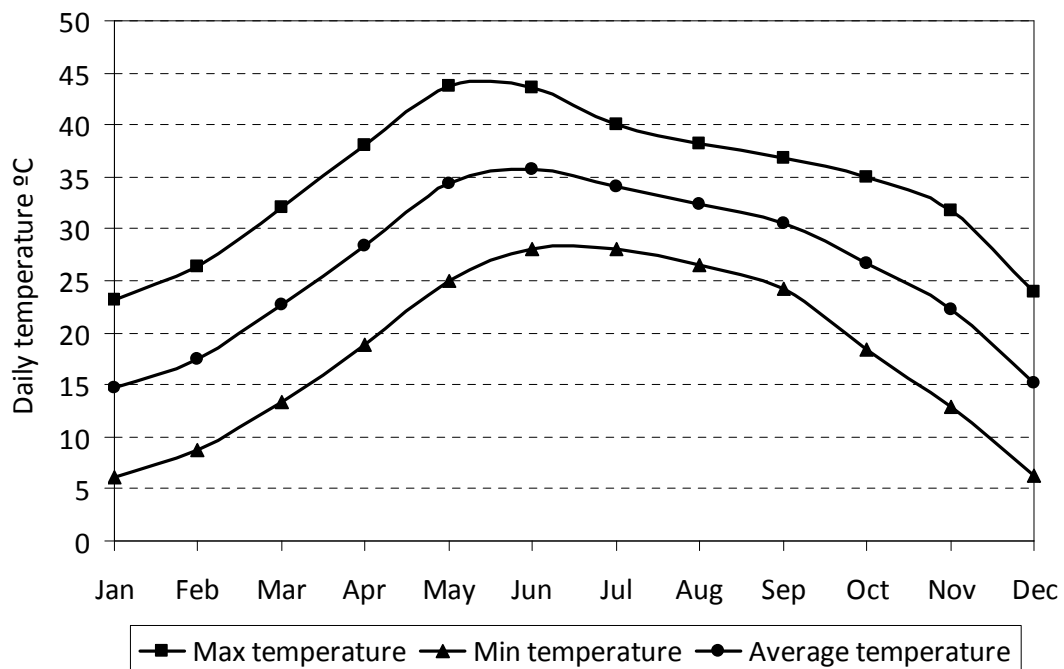
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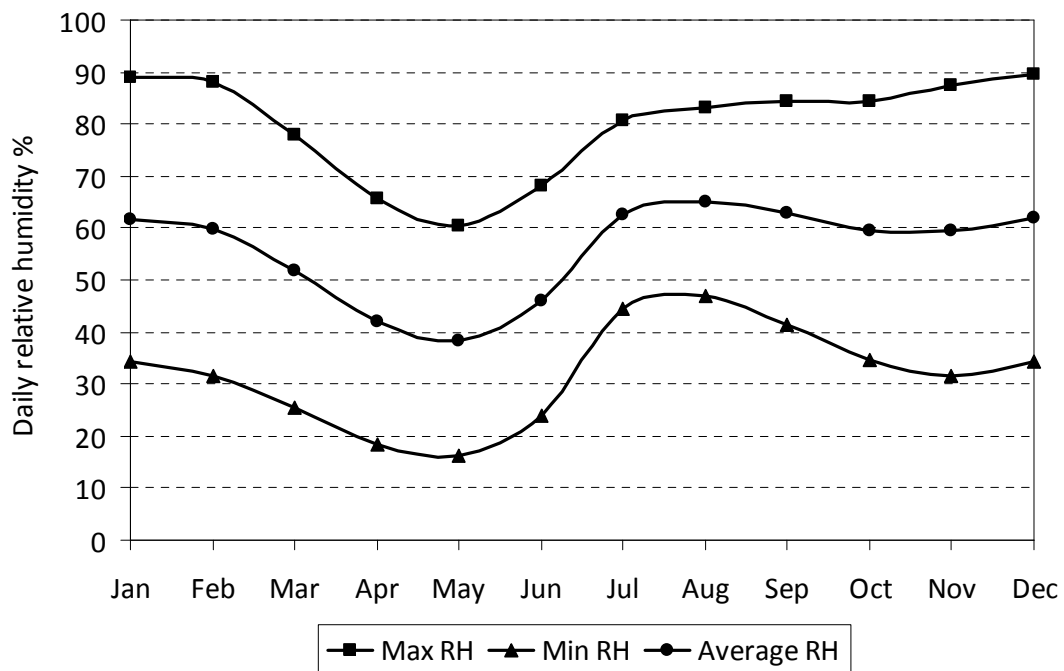
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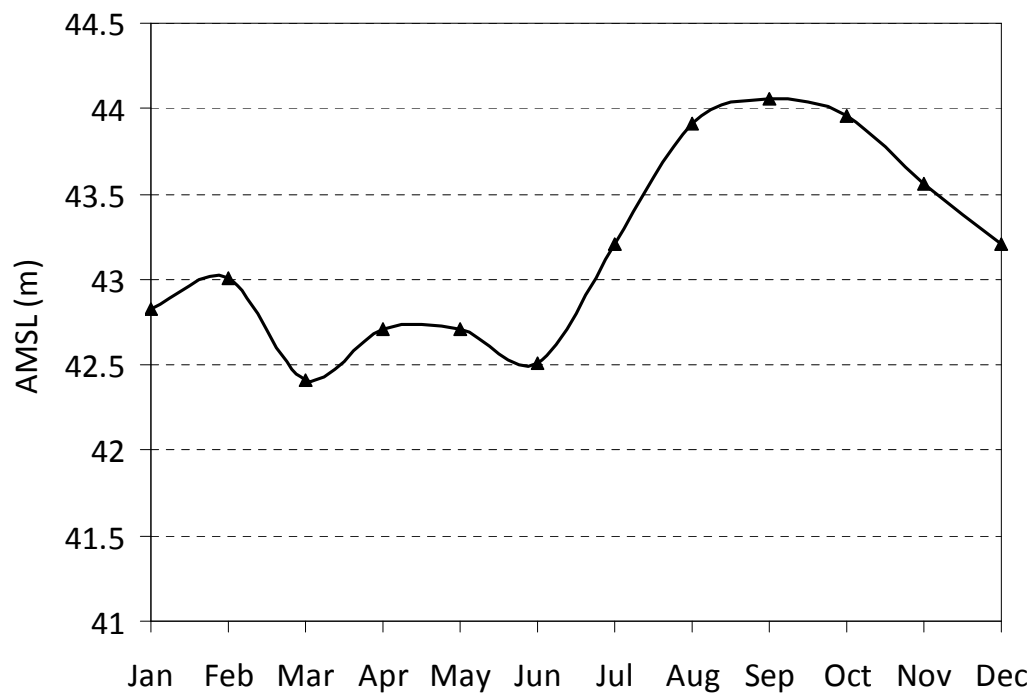
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**Table 1. Grain size distribution of clayey and silty soil. International limits were adopted in the analysis of soil as described by Teutonico (1985)**

	Clayey soil (%)	Silty soil (%)
Clay (<0.002mm)	50.1	21.7
Silt (0.02-0.002mm)	42.9	38.3
Sand (2-0.02mm)	7	40
Gravel (>2mm)	0	0

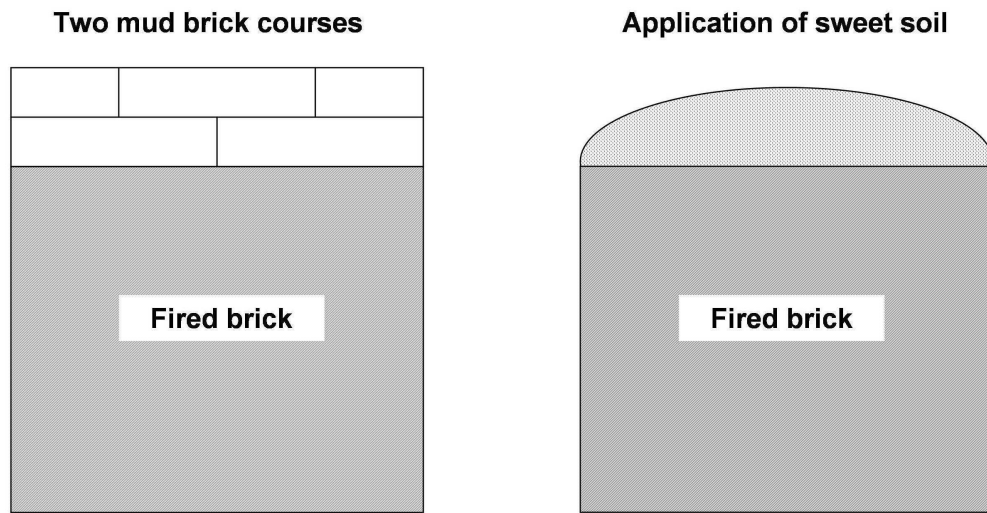


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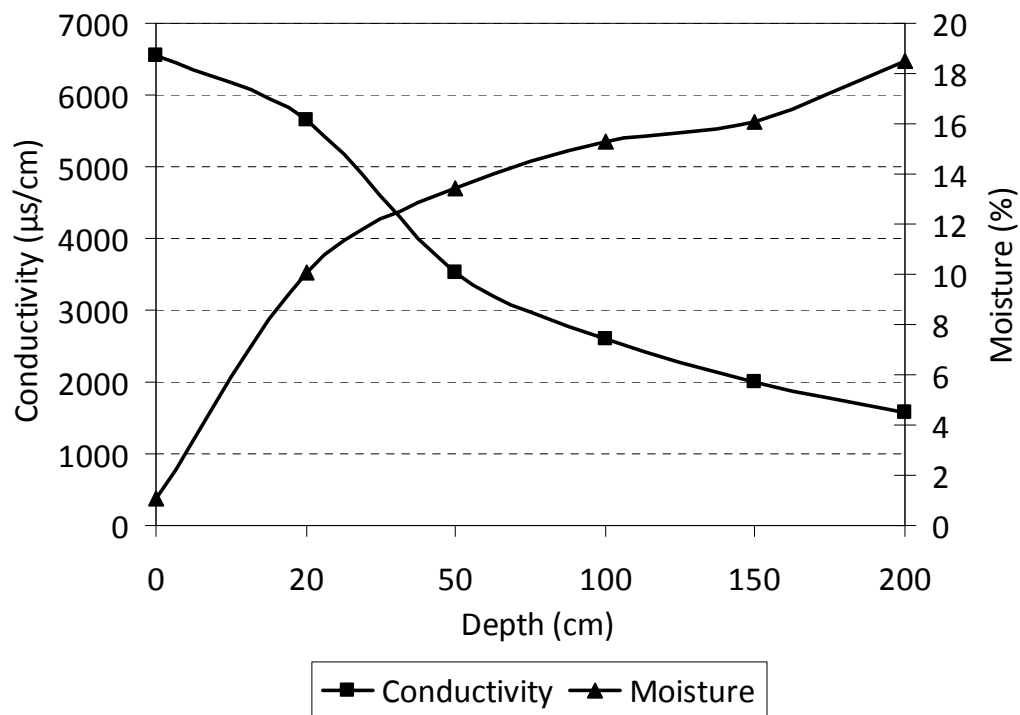




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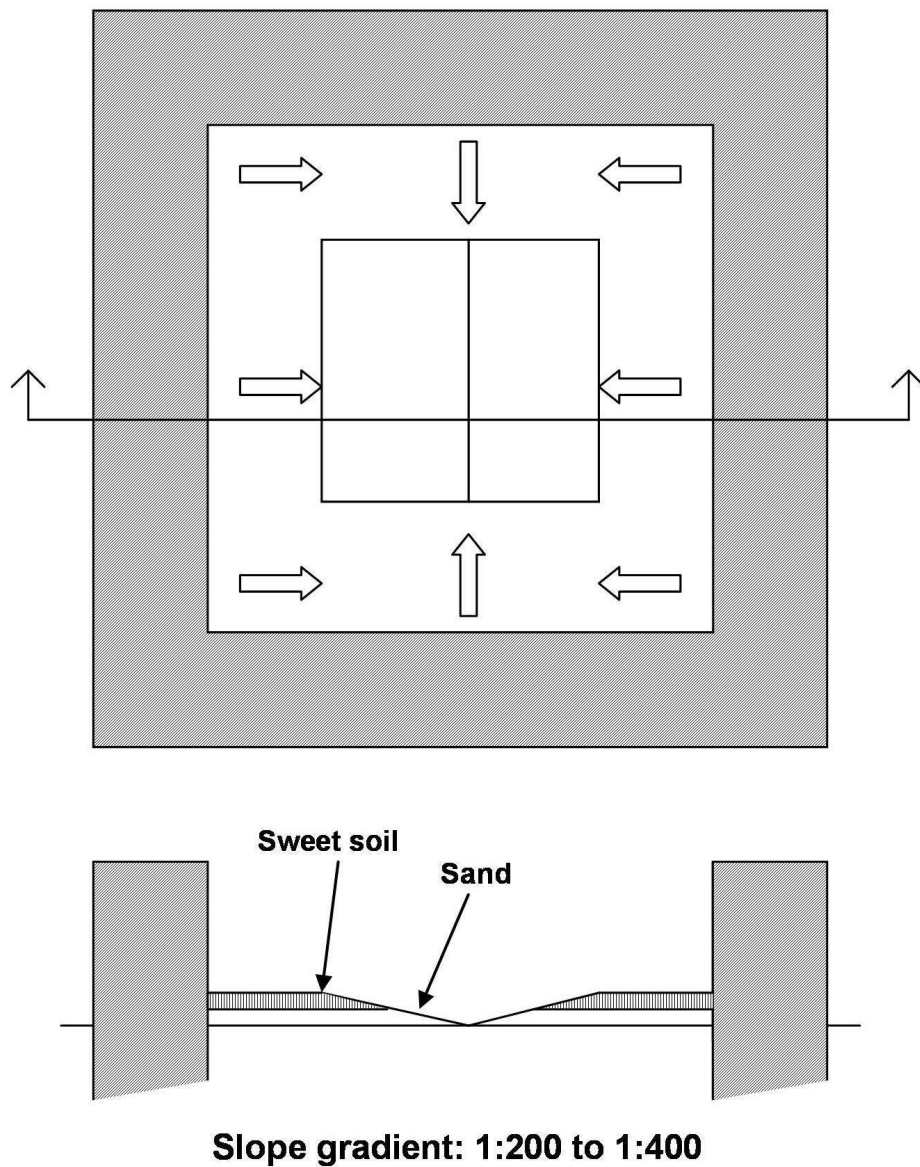


**Fig. 10 Archival picture showing insertion of cementitious damp proof coursing**





**Fig. 11 Creation of shallow ponding (DKG-South area)**



**Fig. 12. Schematic description of shallow ponding in plan and section**

**Table 2. Table showing conductivity and total dissolved salts of soil samples (24 hours)**

Source of soil sample	Conductivity ( $\mu\text{s}/\text{cm}$ )	Total Dissolved Salts
Tajal Syal, Gaji Dero village	1230	615
Tajal Syal, Gaji Dero village	2440	1220
Tajal Syal, land of Noor Ahmed Mashori, village Haji Mashori near Mandyoan	205	102
Allah Rakhio Abro, land of Lalo Brohi near Village Bagi	370	185

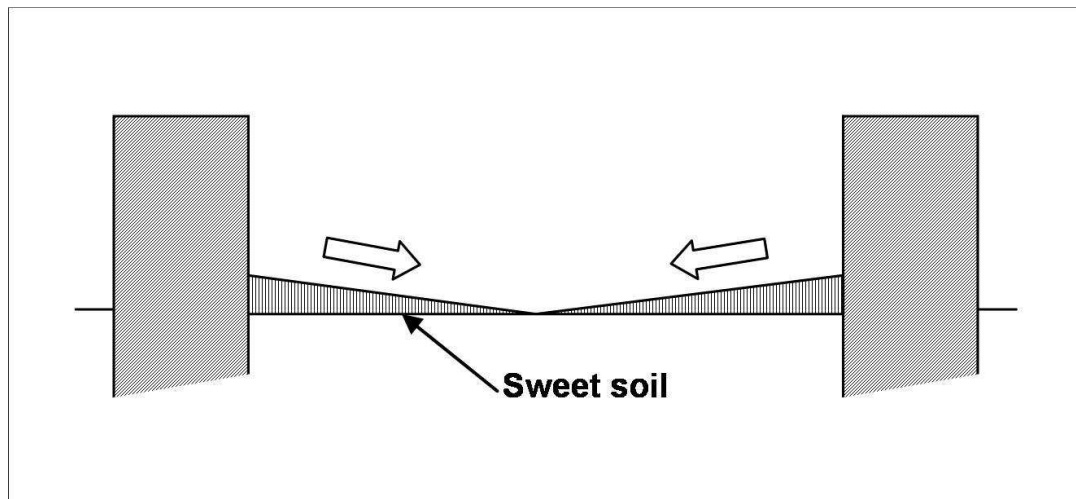


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<sup>1</sup> Moenjodaro's coordinates are N 27° 19.378', E 068° 08.154'.

<sup>2</sup> Construction techniques are discussed in greater detail by Fodde and Khan (2010).

<sup>3</sup> Ge and Krpan (2007) define wind driven rain as follows:

*'Wind-driven rain, also referred to as driving rain, is the amount of rainwater that impinges on a vertical wall surface under the influence of wind and is an important environmental condition for building envelope design. It is hard to quantify accurately because of complex interactions between wind and rain and the buildings themselves. Driving rain is affected by the rain and wind characteristics, including rainfall intensity, duration and frequency of rain event, and wind speed and direction. It is also affected by the building characteristics, including topography, building geometry, sheltering provided by surroundings, façade orientation, and location on the façade.'*

<sup>4</sup> However, a recent study of Indus valley cities by Petersen (2012) explains that there is no correlation between defence against flooding and ramparts, bastions, or fortifications: military and symbolic functions are attributed to them so debate is still ongoing. Investigating platforms and studying their role in the management of water is essential for understanding how to deal with heavy rain, an aspect that was not fully studied in Moenjodaro.

<sup>5</sup> Vergas (1988) suggests that a survey of these historic drains, dating to the Indus period, be carried out and compared to the drainage system that was implemented by the Department of Archaeology.

<sup>6</sup> The clayey soil is quarried in areas such as Malukshah and Noorshah, and the silty soil is quarried in the Indus banks or from the fields of Mashori village.

<sup>7</sup> With total length of 2954m.

<sup>8</sup> After repointing work is concluded, walls are treated with a mud slurry of 2-3mm thickness. Application is carried out as follows (see also Fodde and Khan 2010): after removing eventual salt crystals and dust with a soft brush from the wall base, a first layer of mud slurry is applied by

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splashing it on the whole wall. After drying, a second layer is applied at the wall base so that to provide a proper sacrificial layer where salt weathering is more active. As for the recipe, mud slurry is made with one part of soil and one part of water and for obvious reasons application is avoided in very hot or rainy days. Clayey soil is employed for the slurring and its grain size distributon is that provided in Table 1.

<sup>9</sup> The neighbouring Dadu Canal generally flows at 47m (AMSL). This clearly indicates that the canal flows at the same level as the site ground.

<sup>10</sup> Another measure could be the diversion of water through the disposal channel towards the south and north drain around the site. This would allow proper irrigation of the vegetation that will be planted in the barren areas and would provide fencing against animals. This is possible because the gradient of the disposal channel can be reversed due to the silting of the channel itself. But before doing this, the south and north drains should be repaired. An option could be the connection of the southern drain to the Khair Wah channel on the southern side of village Dhand and crossing the Balhriji road where a pipe has already been fixed by the Commissioner of Larkana. In so doing there would be no problem of gradient, it would be a cheaper option, and the Dadu canal water would be the best available for the irrigation of the area. Plantation is often discussed as a remedial measure against soil erosion, but so far no implementation measures were carried out apart from a botanical survey (Fodde and Khan 2010).